Assessment of Soil–Structure Interaction Effects on Steel Frames Retrofitted with TADAS Yielding Dampers

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Abstract

This study investigates the seismic performance of three- and nine-story steel moment-resisting frames retrofitted with Triangular Added Damping and Stiffness (TADAS) yielding dampers, with a specific focus on the effects of soil–structure interaction (SSI). Nonlinear time history analyses (NLTHA) were conducted under DBE and MCE seismic hazard levels, examining three scenarios: bare frames, damped frames on a rigid base, and damped frames with SSI. Results indicate that while TADAS dampers effectively reduce inter-story drifts and base shear, the inclusion of SSI introduces additional flexibility to the system, increasing period and drift demands—especially at lower stories in mid-rise buildings. The study highlights the necessity of considering SSI in seismic retrofit designs to avoid underestimating deformation demands and ensure realistic performance evaluation.

Keywords

Soil-Structure Interaction, TADAS Yielding Damper, Steel Moment Frame, Time-History Analysis, Seismic Hazard Level

1. Introduction

Modern seismic retrofitting techniques emphasize energy dissipation devices like TADAS dampers, which allow for targeted energy absorption through controlled plastic deformation of triangular steel plates. These devices enhance seismic resilience without altering the primary structural system. However, soil–structure interaction (SSI), particularly in soft soils, can significantly affect the dynamic response by increasing system flexibility, thus altering period, drift, and acceleration demands [1], [2]. In real scenarios, the interaction between foundation and supporting soil alters stiffness and damping properties, contradicting the assumption of fixed-base behavior. Recent studies reveal that SSI can amplify inter-story drifts at lower levels and reduce acceleration demands at upper floors. As a result, over-reliance on fixed-base models can lead to inaccurate seismic assessments. Recent codes such as ASCE/SEI 7-22 emphasize incorporating SSI into design, especially for mid- and high-rise structures. Ahmadi et al. [3] confirmed that neglecting SSI leads to unconservative drift predictions in retrofitted frames. This study evaluates the combined effects of TADAS dampers and SSI using nonlinear dynamic analysis of standard SAC benchmark frames.

2. Methodology

This study analyzes two SAC benchmark frames with 3 and 9 stories, representing low- and mid-rise structures [4].Each was assessed in three configurations: (1) a bare frame (SAC), (2) a frame retrofitted with TADAS dampers assuming a rigid base (SAC/DAM), and (3) a frame with dampers and soil–structure interaction (SAC/DAM/SSI). TADAS dampers were modeled based on Tsai's yielding mechanism [5], ensuring foundation (BNWF) model, incorporating nonlinear soil springs calibrated according to a bilinear hysteretic response under cyclic loading. Nonlinear time history analyses (NLTHA) were conducted using OpenSees, with seven SAC ground motion records applied for both DBE and MCE hazard levels [6].The SSI effects were simulated using a beam-on-nonlinear-Winkler- ASCE/SEI 7-22 recommendationsParameters such as damping ratio, yield force, and damper stiffness were derived to match performance targets and were applied consistently across configurations to isolate the influence of SSI. Figure 1 illustrates the floor plans and elevations of the selected 3- and 9-story SAC frames used for the validation and dynamic analysis stages.

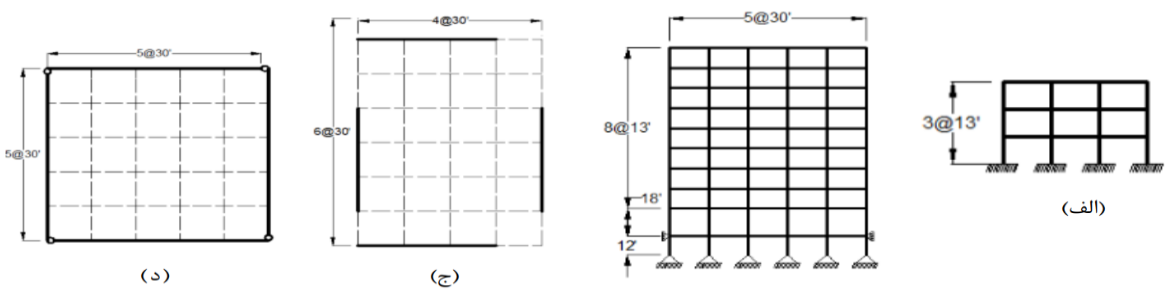

Figure 1. Plans and elevations of 3 and 9 story SAC frames

3. Results and Discussion

Table 1 summarizes the variations in seismic responses across different retrofit configurations and hazard levels. It clearly illustrates the reduction in drift and base shear when TADAS dampers are employed. More importantly, it shows how SSI alters the effectiveness of these dampers by increasing drift demands, particularly at the lower stories. For instance, in the 9-story frame under MCE, drift reduction decreases 9%

when SSI is included. This trend suggests a non-uniform impact of soil flexibility, depending on building height and seismic intensity. Hence, designers must consider SSI to accurately predict retrofit efficiency.

Table 1. Summary of seismic performance across configurations

Frame Type	Hazard Level	Configuration	Drift Change (%)	Base Shear Change (%)
3-Srory	DBE	With Damper	-11	-7
		With Damper + SSI	-7	-11
9-Story		With Damper	-17	-8
		With Damper + SSI	-10	-14
3-Story	MCE	With Damper	-36	-5
		With Damper + SSI	-33	-8
9-Story		With Damper	-12	-5
		With Damper + SSI	-9	-10

4. Conclusion

The implementation of TADAS yielding dampers substantially enhances the seismic resilience of steel frames by effectively reducing inter-story drifts and base shear demands through controlled energy dissipation. Nevertheless, incorporating soil–structure interaction (SSI) alters the dynamic characteristics of the system by increasing flexibility and lengthening fundamental periods, particularly in mid- and high-rise structures. The findings underscore that neglecting SSI can result in underestimation of drift demands and unintended amplification of floor accelerations. Therefore, to achieve accurate performance-based seismic evaluations and ensure reliable retrofit strategies, it is imperative that SSI effects be explicitly considered in both modeling and design stages of structural assessment.

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